

DISPLAY INTERFACE CONCEPTS FOR AUTOMATED FAULT DIAGNOSIS

Michael T. Palmer

December 1989

(NASA-TM-101610) DISPLAY INTERFACE CONCEPTS
FOR AUTOMATED FAULT DIAGNOSIS (NASA) 34 p
CSCL 010

N90-15102

Unclass
0256748

G3/06



National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

SUMMARY

This report describes an effort which investigated concepts for displaying dynamic system status and fault history (propagation) information to the flight crew. This investigation was performed by developing several candidate display formats and then conducting comprehension tests to determine those characteristics that made one format preferable to another for presenting this type of information. Twelve subjects participated. Flash tests, or limited time exposure tests, were used to determine the subjects' comprehension of the information presented in the display formats. It was concluded from the results of the comprehension tests that pictographs were more comprehensible than both block diagrams and text for presenting dynamic system status and fault history information, and that pictographs were preferred over both block diagrams and text. It was also concluded that the addition of this type of information in the cockpit would help the crew remain aware of the status of their aircraft.

INTRODUCTION

Problem Statement

Advances in the technologies of Artificial Intelligence (AI) software and Cathode Ray Tube (CRT) cockpit instrumentation hardware have produced a unique situation. New and potentially useful types of information are capable of being generated by a fault monitoring and diagnosis system connected to the aircraft (ref. 1), and electromechanical dials and gauges are no longer the only media available for displaying information to the flight crew. However, the problem remains of exactly how to present the new types of information generated by advanced diagnostic systems.

Efforts have been made to design display formats for cockpit CRTs to convey system status information to the flight crew (refs. 2,3). But these new formats are still limited to displaying the current state of the aircraft. No provision is made for displaying the dynamics of fault propagation through aircraft systems, nor for taking into account the uncertainty associated with sensor input.

Background

A research effort is currently underway in the Vehicle Operations Research Branch at NASA Langley Research Center to investigate the application of AI to flight management for improved safety and efficiency. This effort is focused primarily on civil transport aircraft operations. Several application areas exist within this focus that may benefit from AI, including: fault monitoring and diagnosis, planning and replanning, and communications management (ref. 4). An application presently being explored is automated fault monitoring and diagnosis, with an emphasis on crew aiding and decision support.

The flight domain presents many problems concerning the use of established AI technology, such as expert systems, for fault diagnosis.

The most obvious challenge is that the situations are dynamic; that is, the status of the aircraft is constantly changing. Facts known to be true at a given time cannot be assumed to be true later in time. Also, sensors are installed only on a limited number of aircraft components, so diagnosis must often be performed with incomplete information. Thus, the dynamic and uncertain nature of the flight domain requires a new approach to fault monitoring and diagnosis that accounts for these factors.

An automated fault monitoring and diagnosis concept that takes into account the dynamic and uncertain nature of the flight domain has been developed in the Vehicle Operations Research Branch. The general framework for this concept, as shown in figure 1, includes several distinct functions: a fault monitoring function, a fault diagnosis function, a recovery planning function, and an interface function (ref. 1).

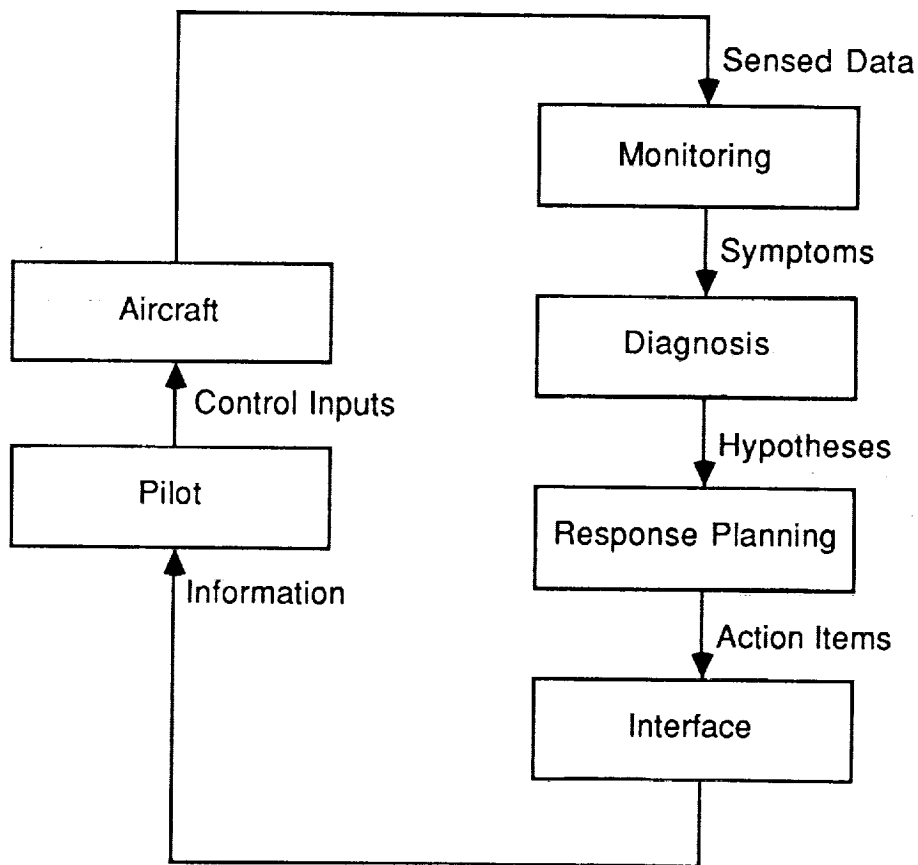


Figure 1. General Framework for Automated Fault Monitoring and Diagnosis.

The fault monitor analyzes aircraft sensor data to determine if an abnormal situation exists. The fault diagnosis function determines the cause or source of the problem, the affected aircraft components, and the propagation path of the fault through the aircraft systems. The response planner analyzes the diagnosis and determines the best course of action to compensate for the problem, and the interface function relays this system status, diagnosis, and response information to the flight crew.

Research Objective

The specific objective of the research described in this report was to support the development of the interface mechanism, in the above framework, by investigating concepts for displaying dynamic system status and fault history (propagation) information to the flight crew. This investigation was performed by developing several candidate display formats and then conducting comprehension tests to determine those characteristics that made one format preferable to another for presenting this type of information.

It should be noted that the display of dynamic system status and fault information is only one of many research issues involved in presenting fault monitoring and diagnosis information. Other issues include: methods for presenting alternative hypotheses, prioritizing hypotheses based on some measure of likelihood, providing an explanation capability of the process used to reach a particular conclusion, and displaying the actual cause of a fault. All these issues are important, but their consideration was beyond the scope of this report.

TECHNICAL APPROACH

Overview

The following approach was taken to investigate concepts for the display of dynamic system status and propagation information. First, the general information requirements of the flight crew were identified with regard to a major aircraft system. The system chosen for this study was a generic turbofan engine. Once these crew information requirements were identified, display format concepts were developed to fulfill them. A generalized fault display interface program was then designed and implemented to provide the hardware display of these format concepts. Next, a series of tests was conducted to measure subject comprehension of the information presented in the different formats. The results of these tests were then analyzed to determine the display format characteristics that resulted in the best comprehension.

Information Requirements

The first step in the approach was to identify the information requirements of the flight crew with regard to fault diagnosis and system status. These information requirements were derived from the results of previously conducted interviews with experienced airline and test pilots. From the results of these interviews (ref. 4), the information requirements of the crew can be summarized as follows:

- (1) the crew wants to know what systems have failed or are affected by a failure;
- (2) they want to know what systems are likely to fail in the near future; and
- (3) they want to know what the severity of the failure is (what capabilities remain).

Display Formats

Two distinct types of display formats were identified as being necessary to fulfill the crew information requirements. The first type is a system status display, which shows the components affected by a failure and the severity of the component failures. Since a system status display will include all major components of a particular system, the remaining capability of that system may be inferred by noting which components are unaffected. The second type of display format is a fault history display, which shows a summary of the changes in the status of the system components. The propagation path of a fault through a particular system is detected from this fault history display, which allows the crew to infer which components may be affected next.

For the system status type of display, two different display formats were developed. The first format used pictographs to represent the system (fig. 2). A pictograph is a graphical representation of a component or system that depicts its actual physical appearance or function. The second system status display format used block diagrams to represent the system (fig. 3). A block diagram represents the functional relationship between components in a system, but does not necessarily depict the actual physical appearance or function of that system.

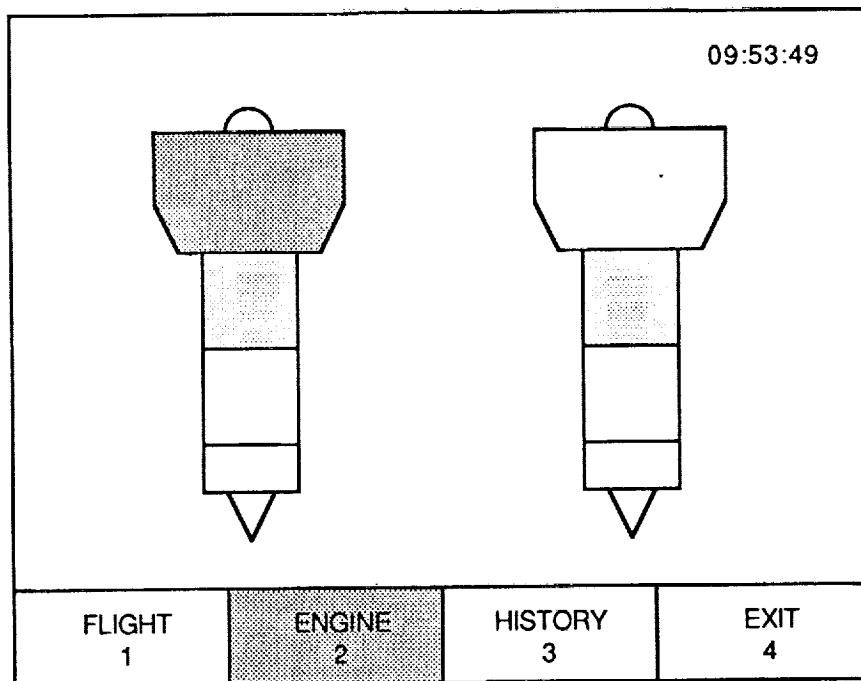


Figure 2. Pictograph System Status Format.

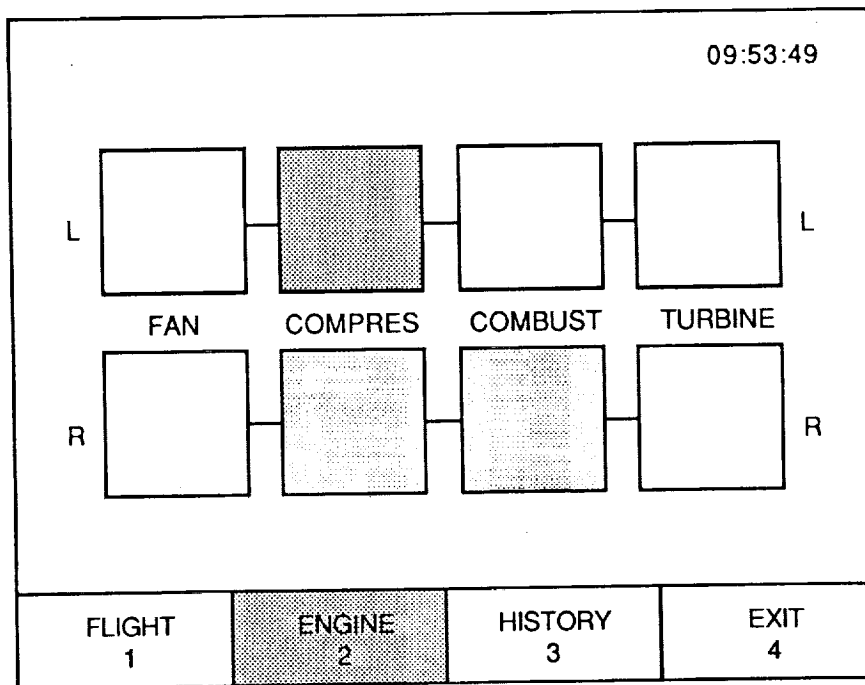


Figure 3. Block Diagram System Status Format.

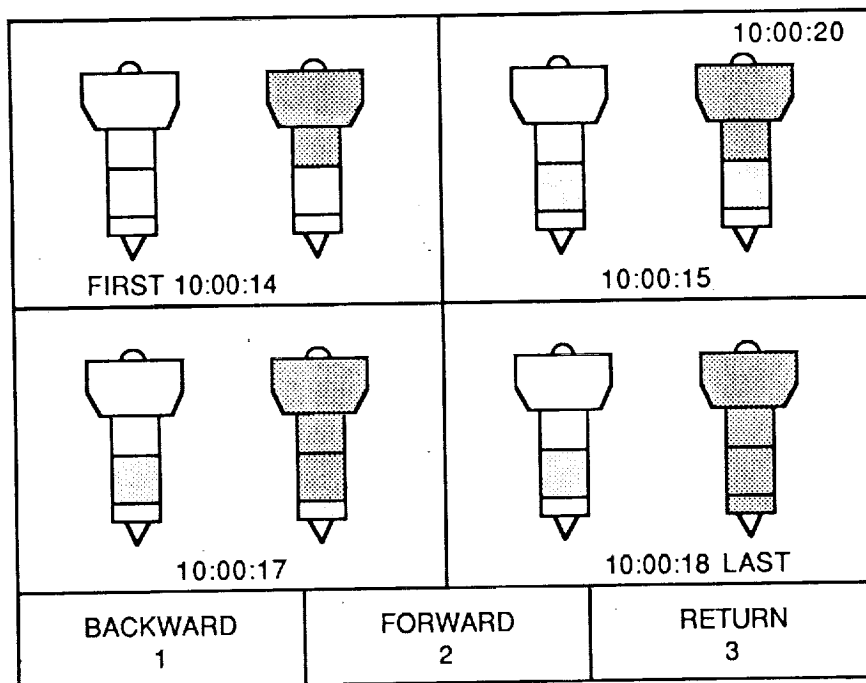


Figure 4. Pictograph Frames Fault History Format.

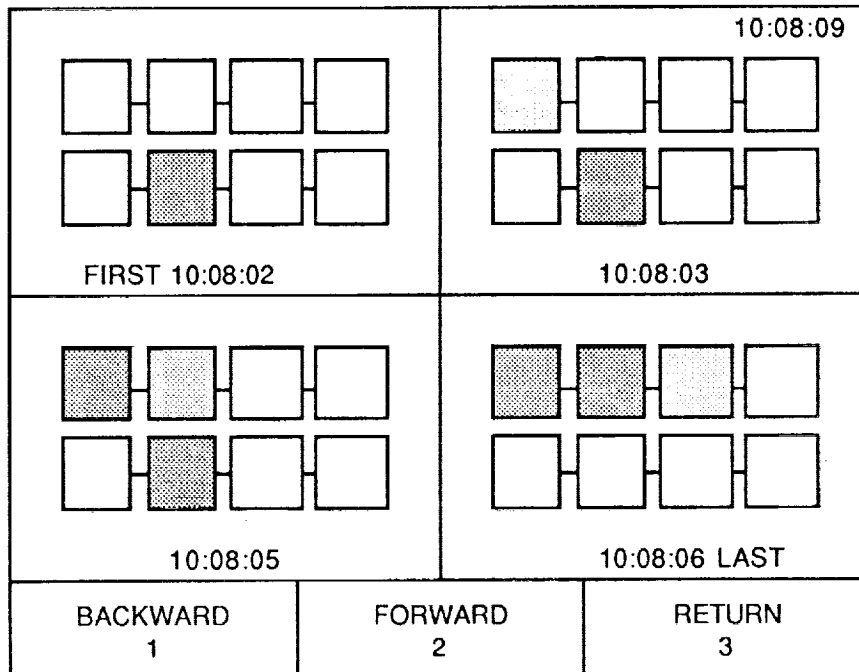


Figure 5. Block Diagram Frames Fault History Format.

SUBSYSTEM NAME	STATUS	TIME
left_fan	failed	10:18:25
left_combustor	failed	10:18:25
right_compressor	partially_failed	10:18:26
right_compressor	failed	10:18:28
right_turbine	failed	10:18:29
		10:18:30

Figure 6. Textual Fault History Format.

For the fault history type of display, three different display formats were developed. The first two of these formats used four fault frames; each frame is a snapshot of the system status taken every time a change in status of one or more system components occurred. The four frames are shown on the screen simultaneously, and show the recent history of the faults in that system. The first fault history display format used pictographs to represent the system in the fault frames (fig. 4), while the second fault history display format used block diagrams (fig. 5). The third fault history display format used text (fig. 6). Here, instead of graphically representing the system using pictographs or block diagrams, the names of the components, their new status, and the time of change in status were listed in chronological order.

In the display formats that used pictographs or block diagrams, color was used to differentiate between components with different status. Red was used to indicate the total failure of a component, amber was used to indicate a partial failure of a component (that is, a component that is still operating but only at reduced capability), and no color to indicate a fully operational component. The outlines of all component diagrams were drawn in green. The textual fault history display format, however, did not use color. Instead, the new status of each component was listed with the component name and the time of the change in status.

The general form of the pictograph formats was developed in accordance with the format guidelines prescribed by Summers and Erickson (ref. 2), except that fully operational components were not shaded green. Concepts were also borrowed from Way, Hornsby, et al. (ref. 3), regarding the screen layout of the pictograph engine display format.

Fault Display Interface Program

A fault display interface program was designed and implemented to generate the various display formats and to display on them the information generated by the fault diagnosis system. It also provided user interaction capability in the form of graphic menus for selecting the system status or fault history display format screens of different aircraft systems. Since this investigation was conducted independently of the development of the fault diagnosis function in the general fault monitoring and diagnosis framework, simulated fault diagnoses were provided by using multiple data files. However, the source of the fault diagnosis information was transparent to the test subject.

The program itself was designed to be independent of the system being represented and the display formats being used. This was accomplished by storing, in separate data files, all the system hierarchy and format (screen layout) information for the different display formats (see fig. 7). The flexibility inherent in the design of the fault display interface program makes it useful as a tool for developing future display formats.

The fault display interface program was implemented in Pascal on an IBM-PC, using the TurboPascal programming environment (ref. 5). A Color Graphics Adapter (CGA) card, with 320 x 200 pixel screen resolution, and compatible color monitor were used to display the program output.

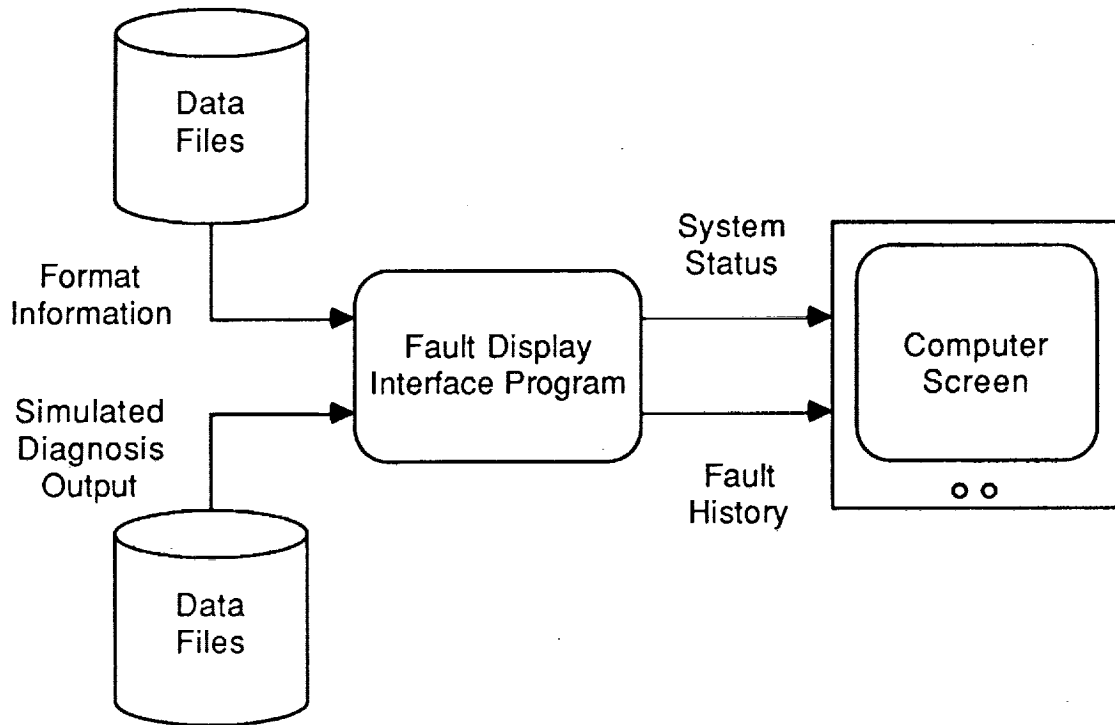


Figure 7. Fault Display Interface Program Schematic.

EXPERIMENT DESIGN AND PROCEDURE

Test Design

To analyze subject comprehension of the information in the two types of display formats, two separate experiments were conducted. The first was a single-factor two-level experiment which compared the two system status display formats: pictographs and block diagrams (see fig. 8). The second was a single-factor three-level experiment which compared the three fault

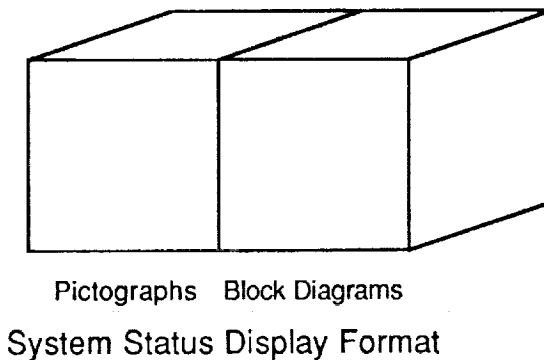


Figure 8. Block Diagram of System Status Display Experimental Design.

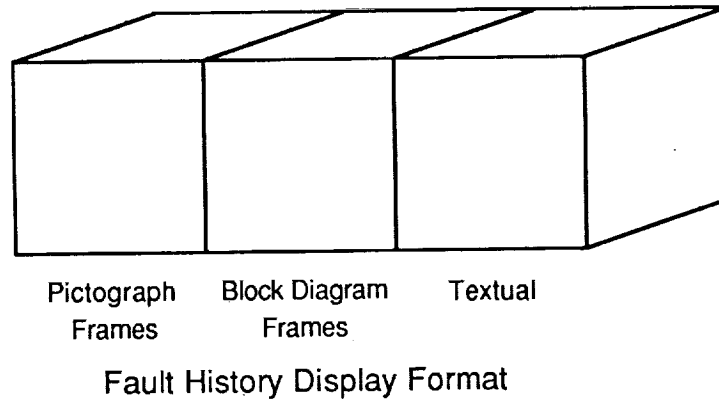


Figure 9. Block Diagram of Fault History Display Experimental Design.

history display formats: pictograph frames, block diagram frames, and the textual format (see fig. 9). The ordering of the testing sequence in each of the two experiments was counterbalanced to prevent ordering bias and reduce the effects of learning (see Table 1). Each display format in the two experiments was tested a total of 36 times.

Subject	Format Testing Sequence	
	Experiment 1	Experiment 2
1	B1,B2,B3,P1,P2,P3	HB1,HB2,HB3,HP1,HP2,HP3,HT1,HT2,HT3
2	P1,P2,P3,B1,B2,B3	HT1,HT2,HT3,HB1,HB2,HB3,HP1,HP2,HP3
3	B1,B2,B3,P1,P2,P3	HP1,HP2,HP3,HT1,HT2,HT3,HB1,HB2,HB3
4	P1,P2,P3,B1,B2,B3	HB1,HB2,HB3,HT1,HT2,HT3,HP1,HP2,HP3
5	B1,B2,B3,P1,P2,P3	HP1,HP2,HP3,HB1,HB2,HB3,HT1,HT2,HT3
6	P1,P2,P3,B1,B2,B3	HT1,HT2,HT3,HP1,HP2,HP3,HB1,HB2,HB3
7	P1,P2,P3,B1,B2,B3	HB1,HB2,HB3,HP1,HP2,HP3,HT1,HT2,HT3
8	B1,B2,B3,P1,P2,P3	HT1,HT2,HT3,HB1,HB2,HB3,HP1,HP2,HP3
9	P1,P2,P3,B1,B2,B3	HP1,HP2,HP3,HT1,HT2,HT3,HB1,HB2,HB3
10	B1,B2,B3,P1,P2,P3	HB1,HB2,HB3,HT1,HT2,HT3,HP1,HP2,HP3
11	P1,P2,P3,B1,B2,B3	HP1,HP2,HP3,HB1,HB2,HB3,HT1,HT2,HT3
12	B1,B2,B3,P1,P2,P3	HT1,HT2,HT3,HP1,HP2,HP3,HB1,HB2,HB3

Legend:

Bx, Px = Displays using Block Diagram or Pictograph format
 HBx, HPx, HTx = Displays using Block Diagram Frame, Pictograph frame,
 or Textual history format

Table 1. Test Sequence Ordering for the Various Formats Tested.

Test Subjects

Twelve test subjects participated in the experiments. Since no specific piloting tasks were needed for this test, a combination of pilots and non-pilots was used. Seven of the twelve test subjects were licensed pilots, with qualifications ranging from a Private Pilot License with 95 hours total flight time to an Airline Transport Pilot (ATP) License with over 8,000 hours total flight time (see Table 2). Of the other five subjects who were not pilots, four had experience in flight simulators, and all five were generally familiar with aircraft systems and operating procedures. Because of the small number and, in some cases, limited backgrounds of the test subjects in this study, the results cannot necessarily be generalized to the much larger population of operational pilots. However, the intent of this research was to investigate new concepts for displaying dynamic system status and fault history (propagation) information, and not to test specific formats that are candidates for imminent operational use.

Subject	Pilot	License & Ratings	Flight Time	Flown Simulator	Simulator Time	Familiar w/Aircraft
1	No	Com/Ins ATP Private	450 2700 95	Yes	1	Yes
2	Yes			Yes	50	Yes
3	Yes			Yes	1000	Yes
4	Yes			Yes	2	Yes
5	No	ATP Private Private	8000 300 100	No	2000	Yes
6	No			Yes		Yes
7	No			Yes		Yes
8	Yes			Yes		Yes
9	Yes	Private	4000	No	200	Yes
10	Yes			Yes		Yes
11	No			Yes		Yes
12	Yes			Yes	110	Yes

Legend:

PRIVATE = Private Pilot's License
COM = Commercial Pilot's License
ATP = Air Transport Pilot's License
INS = Instrument Rating

Table 2. Summary of Test Subjects' Experience

Test Procedure

The test procedure for each subject is shown in Table 3. The major steps in the procedure are described in more detail in the following paragraphs, and all written test materials are included in Appendix A.

Each subject first received a short briefing on the overall research effort and the purpose of this particular series of experiments. The subject then filled out a background information questionnaire to record his pilot qualifications or aircraft-related experience. Also, before the tests began, each subject completed a questionnaire to record his ideas of what information would be useful from an automated fault diagnosis system, and how that information should be presented. This questionnaire was filled out by each subject before he had seen any of the display formats to be tested in the experiments.

The display format comprehension tests were then conducted. Each test consisted of a series of flash tests for each display format. Each flash test, or limited time exposure test, was performed by presenting the display format for a short, measured amount of time on the CRT screen. Immediately after the image was erased, the test subject filled out a questionnaire (designed for that display format type) to record his comprehension of the information presented. A separate and simplified version of the fault display interface program was used to generate the displays for the flash tests.

Step	Description
1	Introduction to research effort and current experiment.
2	Background information questionnaire.
3	Questionnaire prior to tests.
4	Discuss first system status format.
5	Test1, test2, test3.
6	Discuss second system status format (handout).
7	Test4, test5, test6.
8	Discuss first fault history format (handout).
9	Test7, test8, test9.
10	Discuss second fault history format (handout).
11	Test10, test11, test12.
12	Discuss third fault history format (handout).
13	Test13, test14, test15.
14	Detailed introduction to fault display interface program.
15	Scenario1, scenario2.
16	Subjective evaluation.

Table 3. Steps in Testing Procedure for Each Subject.

Three flash tests were performed for each of the two system status display formats (pictographs and block diagrams) for the first experiment. Each of the three flash tests presented a different system status on the display format being tested, and the duration of each exposure was 1 second. Before being tested on each format, the subject was allowed to study the format layout. Three flash tests were also performed for each of the three fault history display formats (pictograph frames, block diagram frames, and text) for the second experiment. Each of the three flash tests presented a different final system status and fault propagation path on the display format being tested. Because of the increased amount of

information on the fault history formats, the duration of the exposure was lengthened to 5 seconds. Again, the subject was allowed to study each format layout before being tested on it.

After all flash tests were completed for each subject, the subject then participated in an interactive session with the fault display interface program. During this session, the program generated a dynamic fault scenario in fast-time simulation (the frequency of faults was much higher than would normally be expected). The fault scenario itself was designed to demonstrate the interactive capability of the fault display interface program, and was not meant to necessarily represent any real or expected series of events. No experimental data was collected from these interactive sessions; rather, they were included in this study to elicit subjective observations from the subjects about the interface mechanism concepts.

At the conclusion of all the tests, each subject completed a subjective evaluation in the form of a structured questionnaire. This evaluation consisted of three parts. The first part contained seven multiple choice questions covering the operation of the fault display interface program, the two system status and three fault history display formats, and the usefulness of fault history information. The second part contained two short-answer/essay questions asking how the test subject would improve the display formats and the menu interface of the fault display interface program. The final part contained a single question asking the subject to rank the three features liked best and the three features liked least about the display formats.

RESULTS AND DISCUSSION

Flash Tests

System Status Display Formats (Experiment 1) - The tabulated results of the first experiment are shown in Tables 4a and 4b. The results show that comprehension was high for both display formats: 80 percent for the pictograph format and 88 percent for the block diagram format. The results also show that the test scores for the block diagram format were on average 10 percent better than those for the pictograph format. When statistical analysis was applied to these results, however, it was found that the difference in scores was not statistically significant. The statistical analysis technique applied was the t-test (ref. 6).

Format	Comprehension (Average Test Score)
Pictographs	80.0 %
Block Diagrams	88.1 %

Table 4a. Test Results of System Status Display Format Experiment.

Comparison	Difference	T-value	Significance
Pictographs vs. Block Diagrams	9.6 %	1.536	None

Table 4b. Comparison of Results for System Status Display Formats.

Even though the block diagram format was found to have a slightly higher comprehension rate than the pictograph format, all test subjects stated that they preferred the pictograph format. One possible explanation for this discrepancy with the test scores is that a very limited amount of information was presented in the system status display formats. The information was so limited, in fact, that many of the subjects confessed that they were ignoring the meaning of the information until they filled out the questionnaire, and were instead relying on pattern recognition. Apparently simple pattern recognition was easier with the block diagram format, although this does not imply that the later interpretation of the pattern was either easier or more difficult than with the pictograph format. The time to fill out the questionnaire was not measured.

An examination of the results of the different test subject groups (pilots vs. non-pilots) revealed that there was no significant difference between the pilots' and non-pilots' test scores for the pictograph format or the block diagram format.

Fault History Display Formats (Experiment 2) - The tabulated results of the second experiment are shown in Tables 5a and 5b. The results show that the overall comprehension level was not quite as high as it was for the system status display formats: 80 percent for the pictograph frames format, 67 percent for the block diagram frames format, and 56 percent for the textual format. The results also show that the test scores for the pictograph frames format were on average 18 percent better than those for the block diagram frames format, and 34 percent better than those for the textual format. The test scores for the block diagram frames format were on average 17 percent better than those for the textual format. When statistical analysis was applied to these results, it was found that: (1) the difference between the pictograph frames format and the block diagram frames format was significant to the 2 percent level (less than a 2 percent chance existed that the difference was coincidental); (2) the difference between the pictograph frames format and the textual format was significant to the 0.5 percent level; and (3) the difference between the block diagram frames format and the textual format was not statistically significant. The t-test was again the statistical analysis technique applied.

Format	Comprehension (Average Test Score)
Pictograph Frames	79.5 %
Block Diagram Frames	66.7 %
Textual	56.4 %

Table 5a. Test Results of Fault History Display Format Experiment.

Comparison	Difference	T-value	Significance
Pictograph Frames vs. Block Diagram Frames	17.6 %	2.412	2 %
Pictograph Frames vs. Textual	34.0 %	4.017	0.5 %
Block Diagram Frames vs. Textual	16.6 %	1.656	None

Table 5b. Comparison of Results for Fault History Display Formats.

The results of this experiment agreed much more closely with the expectations based on subject comments and reaction to the different formats. One possible explanation for the lower performance on the block diagram frames format is that much more information was presented in the fault history display formats compared with the system status display formats. The increase in the amount of information prevented a simple pattern recognition approach, so the subjects had to interpret the information while the display was visible. An examination of the results of the different test subject groups (pilots vs. non-pilots) revealed that the non-pilots' test scores for the textual format were 43 percent better than the scores of the pilots for the same format. This difference in scores was found to be significant to the 1 percent level (T-value = 2.993). There was no significant difference between the pilots' and non-pilots' test scores for the pictograph frames format or the block diagram frames format.

One possible reason which may account for the difference in test scores for the textual format between the pilots and non-pilots is that when presented with information in the textual format, most of the pilots

expressed immediate dislike and may have consciously or unconsciously biased their performance against this format. The non-pilots as a group seemed to try to perform as well as possible on all formats.

Subjective Evaluation

The responses to the first part of the subjective evaluation (see Appendix B) are summarized in Tables 6a and 6b. The Average Response (AR) for each question was calculated by the following formula:

$$AR = \text{SUM}(\text{sum}(a)*4 + \text{sum}(b)*3 + \text{sum}(c)*2 + \text{sum}(d)*1) / (4*N) * 100\%$$

where: AR is the average response,
sum(a) is the number of "(a)" responses given,
sum(b) is the number of "(b)" responses given, etc., and
N is the number of subjects.

The possible responses represent a continuum of most favorable (a) to most unfavorable (d) reaction to each of the features. The average response for a feature is therefore similar to a grade point average.

These responses indicate that: (1) the test subjects thought that the fault display interface program was relatively easy to operate (AR = 90 percent); (2) the subjects preferred the pictograph format (AR = 96 percent) over the block diagram format (AR = 72 percent) for viewing system status information; (3) the subjects preferred the pictograph frames format (AR = 81 percent) over both the block diagram frames (AR = 62 percent) and the textual (AR = 42 percent) formats for viewing fault history information, and preferred the block diagram frames format over the textual format; and (4) the subjects thought that displaying this type of fault history information was useful (AR = 73 percent) for understanding what has happened to a particular system.

Question	Average Response
Overall Operation	89.6 %
Fault Detection:	
Pictographs	95.8 %
Block Diagrams	71.9 %
Propagation Recognition:	
Pictograph Frames	81.3 %
Block Diagram Frames	61.5 %
Textual	41.7 %
Usefulness of Fault History	72.9 %

Table 6a. Summary of Responses to the First Part of the Subjective Evaluation (see Appendix B).

When statistical analysis was applied to these results, it was found that the 29 percent difference between the average responses to the pictograph format and the block diagram format was significant to the 0.5 percent level. It was also found that: (1) the 28 percent difference between the average responses to the pictograph frames format and the block diagram frames format was significant to the 1 percent level; (2) the 64 percent difference between the average responses to the pictograph frames format and the textual format was significant to the 0.5 percent level; and (3) the 38 percent difference in average responses to the block diagram frames format and the textual format was significant to the 5 percent level.

An examination of the responses of the different test subject groups (pilots vs. non-pilots) revealed that no significant differences existed between the pilots' and non-pilots' average responses to any of the subjective evaluation questions regarding the display formats.

Comparison	Difference	T-value	Significance
Pictographs vs. Block Diagrams	28.6 %	5.063	0.5 %
Pictograph Frames vs. Block Diagram Frames	27.8 %	3.035	1 %
Pictograph Frames vs. Textual	64.4 %	4.710	0.5 %
Block Diagram Frames vs. Textual	38.4 %	2.318	5 %

Table 6b. Comparison of Responses from the First Part of the Subjective Evaluation.

The responses to the second part of the subjective evaluation are given in Appendix B, and consist of the comments and suggestions given by the test subjects in response to the two questions in this part. Many of these suggestions were very specific to the formats being tested and the computer program presenting them, but several implied underlying concepts that should be explored in subsequent investigations. These concepts include: automatic selection of displays for systems in which a failure has occurred; inclusion of sensor readings, both pictorial and digital,

directly on the system status formats; and higher level notification of subsystem failures to show their effect on overall aircraft capability.

The responses to the third part of the subjective evaluation (see Appendix B) are summarized in Table 7. The score for each display format characteristic was calculated by the following formula:

$$\text{SCORE} = \text{sum}(1)*3 + \text{sum}(2)*2 + \text{sum}(3)*1 - \text{sum}(4)*1 - \text{sum}(5)*2 - \text{sum}(6)*3$$

where: SCORE is the ranking of each item (a) through (v) in question 10,
 sum(1) is the number of "1" rankings received,
 sum(2) is the number of "2" rankings received, etc.

The possible rankings represent what each test subject thought were the three best (1=best liked,2,3) and the three worst (4,5,6=least liked) features of the display concepts. Possible scores range from 36 down to -36.

Item Description	Score
Amount of information presented	4
Use of color	15
Size of alphanumerics	0
Size of system diagrams	3
Size of history frames	-1
System display format	8
Inclusion of labels on block diagrams	-3
Deletion of labels on pictographs	0
History display format	-6
Menu format	0
Illumination of menu option for changes	12
Ease of switching between display types	-2
Ability to select current system history only	-2
Chronological arrangement of history frames	0
Lack of history info updates	-14
Ordering of history frame pages	-9
Text formats	-12
Use of pictographs	9
Block diagram formats	-2
Absence of flashing menu option	-2

Table 7. Summary of Rankings from the Third Part of the Subjective Evaluation (see Appendix B).

The responses indicate that the test subjects were slightly favorable towards the amount of information presented (SCORE = 4), very favorable towards the use of color (SCORE = 15), neutral towards the size of the alphanumerics (SCORE = 0), slightly favorable towards the size of the

system diagrams (SCORE = 3), and slightly negative towards the size of the history frames (SCORE = -1). The subjects were also favorable to the system display format arrangement (SCORE = 8), slightly negative towards the inclusion of labels on the block diagrams (SCORE = -3), neutral on the deletion of labels on the pictographs (SCORE = 0), and negative towards the history display format arrangement (SCORE = -6). The subjects were neutral towards the menu format arrangement (SCORE = 0), very favorable towards the illumination of menu options for changes in status (SCORE = 12), slightly negative towards the ease of switching between display types (SCORE = -2), and slightly negative towards the ability to select the history of the currently viewed system only (SCORE = -2). The subjects were also neutral towards the chronological arrangement of the history frames (SCORE = 0), very negative towards the lack of information updates while viewing a system history (SCORE = -14), and negative towards the ordering of the history frame pages (SCORE = -9).

In addition to the listed display format characteristics, several characteristics were included by test subjects: the responding subjects were very negative towards the use of text formats (SCORE = -12), favorable towards pictograph formats (SCORE = 9), slightly negative towards block diagram formats (SCORE = -2), and slightly negative towards the absence of a flashing menu option for status change notification (SCORE = -2).

To summarize, the responses to the third part of the subjective evaluation indicated that the test subjects liked the pictograph formats best, liked the use of color for differentiating component status, and liked a form of notification when changes in system status occurred. However, the subjects did not particularly like any of the history formats, did not like the lack of status updates while viewing a system history, and did not like the ordering (oldest first) of the pages of history information. Based on these responses, it is clear that additional research is necessary to examine alternatives for displaying fault history (propagation) information.

CONCLUDING REMARKS

The results of the experiments suggest that pictographs should be used over both block diagrams and text for system status and fault history display formats. The responses to the first part of the subjective evaluation agree with these test results: the subjects stated that they preferred pictographs over block diagrams and text for viewing system status and fault history information. The responses to the second and third parts of the subjective evaluation also agree with the test results, but indicate that much additional research is necessary to resolve specific format and interaction problems.

REFERENCES

1. Palmer, Michael T.; Abbott, Kathy H.; Schutte, Paul C.; and Ricks, Wendell R.: "Implementation of a Research Prototype Onboard Fault Monitoring and Diagnosis System," AIAA-87-2777, October 1987.

2. Summers, Leland G.; and Erikson, Jeffery B.: "System Status Display Information," Douglas Aircraft Company, NASA CR-172347, October 1984.
3. Way, T.C.; Hornsby, M.E.; Gilmour, J.D.; Edwards, R.E.; and Hobbs, R.E.: "Pictorial Format Display Evaluation," Boeing Military Airplane Company, AFWAL-TR-84-3036, May 1984.
4. Baron, Sheldon; and Feehrer, Carl: "An Analysis of the Application of AI to the Development of Intelligent Aids for Flight Crew Tasks," Bolt, Beranek, and Newman, Inc., NASA CR-3944, October 1985.
5. ---: TurboPascal Version 3.0 Reference Manual, Borland International, Inc., 1985.
6. Shneiderman, Ben: Software Psychology, Little, Brown and Company, Boston, 1980.

APPENDIX A
TEST MATERIALS

BACKGROUND INFORMATION

TEST SUBJECT _____

1. Name _____
2. Are you a pilot? Yes _____ No _____
3. If yes, how many total flight hours do you have? _____
4. Please list all ratings _____

5. Have you ever flown a flight simulator?
Yes _____ No _____
6. If yes, give approximate hours and simulator type.

7. Even if you are not a pilot and have never flown a flight simulator before, are you familiar with basic aircraft systems and how they operate?
Yes _____ No _____

QUESTIONNAIRE PRIOR TO TESTS

TEST SUBJECT _____

1. In general, what would you want an automated fault diagnosis system to tell you when it detects that something has gone wrong?

2. How would you want it to present this information to you?

3. What would you want an automated fault diagnosis system to show you so that you could trace the fault history of a particular system?

4. How would you want it to present this fault history information to you?

FLASH TEST NUMBER _____

TEST SUBJECT _____

1. Name the component(s) of the left engine that were failed.

2. Name the component(s) of the left engine that were partially failed.

3. Name the component(s) of the left engine that were okay.

4. Name the component(s) of the right engine that were failed.

5. Name the component(s) of the right engine that were partially failed.

6. Name the component(s) of the right engine that were okay.

(HISTORY) FLASH TEST NUMBER _____

TEST SUBJECT _____

1. In which engine did a fault first occur?

2. Which component(s) in that engine first indicated a fault?

3. Did the initial fault(s) in that engine remain throughout the viewed time interval?

4. Which direction (towards the inlet or towards the outlet) in the engine did the fault(s) seem to propagate? [State N/A if the fault(s) did not seem to propagate.]

5. Which component(s) in the other engine first indicated a fault? [State N/A if no faults were indicated.]

6. Did the initial fault(s) in this engine remain throughout the viewed time interval? [State N/A if no faults were indicated.]

7. Which direction (towards the inlet or towards the outlet) in the engine did the fault(s) seem to propagate? [State N/A if no faults were indicated or if the fault(s) did not seem to propagate.]

SUBJECTIVE EVALUATION

TEST SUBJECT _____

1. How would you rate the overall ease of operating the display program?
 - (a) very easy to operate
 - (b) somewhat easy to operate
 - (c) somewhat difficult to operate
 - (d) very difficult to operate

2. How easy was it for you to detect the faulted subsystems when the information was presented in pictograph form?
 - (a) very easy to detect
 - (b) somewhat easy to detect
 - (c) somewhat difficult to detect
 - (d) very difficult to detect

3. How easy was it for you to detect the faulted subsystems when the information was presented in block diagram form?
 - (a) very easy to detect
 - (b) somewhat easy to detect
 - (c) somewhat difficult to detect
 - (d) very difficult to detect

4. How easy was it for you to recognize the sequence of subsystem faults when the fault history information was presented in the form of four miniature system displays using pictographs?
 - (a) very easy to recognize
 - (b) somewhat easy to recognize
 - (c) somewhat difficult to recognize
 - (d) very difficult to recognize

5. How easy was it for you to recognize the sequence of subsystem faults when the fault history information was presented in the form of four miniature system displays using block diagrams?
 - (a) very easy to recognize
 - (b) somewhat easy to recognize
 - (c) somewhat difficult to recognize
 - (d) very difficult to recognize

6. How easy was it for you to recognize the sequence of subsystem faults when the fault history information was presented in the form of a word list?

- (a) very easy to recognize
- (b) somewhat easy to recognize
- (c) somewhat difficult to recognize
- (d) very difficult to recognize

7. In general, how useful did you find the type of fault history information, presented in the three different forms, to be in understanding what has happened to a particular system?

- (a) very useful
- (b) somewhat useful
- (c) somewhat useless
- (d) very useless

8. How would you improve the screen formats of the display concepts?

9. How would you improve the menu option selection devices of the display concepts?

10. Please rank the three things you liked best about the display concepts (1=best liked,2,3), and the three things you liked least about the display concepts (4,5,6=least liked).

- _____ (a) total amount of information presented
- _____ (b) use of color
- _____ (c) size of alphanumerics
- _____ (d) size of system diagrams
- _____ (e) size of history frames
- _____ (f) system display format
- _____ (g) inclusion of labels on block diagrams
- _____ (h) deletion of labels on pictographs
- _____ (i) history display format
- _____ (j) menu format
- _____ (k) illumination of menu option for system with status change
- _____ (l) ease of switching back and forth between system and history displays
- _____ (m) ability to select the history display for the currently viewed system only
- _____ (n) chronological arrangement of history frames on each page of history information
- _____ (o) lack of updating history information while viewing the history display
- _____ (p) order in which pages of history information are presented
- _____ (q) other _____
- _____ (r) other _____
- _____ (s) other _____
- _____ (t) other _____
- _____ (u) other _____
- _____ (v) other _____

APPENDIX B
SUMMARY OF RESPONSES TO SUBJECTIVE EVALUATION

For questions 1 - 7 of the subjective evaluation, the number of subjects selecting each option (a) - (d) is given in square brackets next to that option.

1. How would you rate the overall ease of operating the display program?

(a) very easy to operate	[7]
(b) somewhat easy to operate	[5]
(c) somewhat difficult to operate	[0]
(d) very difficult to operate	[0]

2. How easy was it for you to detect the faulted subsystems when the information was presented in pictograph form?

(a) very easy to detect	[10]
(b) somewhat easy to detect	[2]
(c) somewhat difficult to detect	[0]
(d) very difficult to detect	[0]

3. How easy was it for you to detect the faulted subsystems when the information was presented in block diagram form?

(a) very easy to detect	[1]
(b) somewhat easy to detect	[8.5]
(c) somewhat difficult to detect	[2.5]
(d) very difficult to detect	[0]

4. How easy was it for you to recognize the sequence of subsystem faults when the fault history information was presented in the form of four miniature system displays using pictographs?

(a) very easy to recognize	[4]
(b) somewhat easy to recognize	[7]
(c) somewhat difficult to recognize	[1]
(d) very difficult to recognize	[0]

5. How easy was it for you to recognize the sequence of subsystem faults when the fault history information was presented in the form of four miniature system displays using block diagrams?

(a) very easy to recognize	[0]
(b) somewhat easy to recognize	[6.5]
(c) somewhat difficult to recognize	[4.5]
(d) very difficult to recognize	[1]

6. How easy was it for you to recognize the sequence of subsystem faults when the fault history information was presented in the form of a word list?

- | | |
|-------------------------------------|-----|
| (a) very easy to recognize | [1] |
| (b) somewhat easy to recognize | [1] |
| (c) somewhat difficult to recognize | [3] |
| (d) very difficult to recognize | [7] |

7. In general, how useful did you find the type of fault history information, presented in the three different forms, to be in understanding what has happened to a particular system?

- | | |
|----------------------|-----|
| (a) very useful | [4] |
| (b) somewhat useful | [4] |
| (c) somewhat useless | [3] |
| (d) very useless | [1] |

For question 8 and 9 of the subjective evaluation, a condensed version of frequent responses is given below each question.

8. How would you improve the screen formats of the display concepts?

Would like to see the partial faults and full failures displayed separately when the distinction between the two is needed.

Use pictographs, add information on screen to indicate why a system is failed (i.e. draw an oil pressure gage showing low pressure).

Use pictographs, and show a fire in the combustor to indicate operation of the engine.

Separate the components on the pictorial display - easier to distinguish.

Make the picture larger.

Rotate block diagram format so they are vertical. Include some digitally displayed information pertaining to system performance.

Rotate block diagrams 90 degrees, and put #1 engine on left side.

Show component that caused the status change by flashing it or something. Only scroll 2 frames instead of 4 in the history.

Top level display should show all major systems (engine, control surfaces, etc.). If the engine fails, this should show up on this display, then you can go to the engine display for details.

Flash most recent and/or unacknowledged failures.

9. How would you improve the menu option selection devices of the display concepts?

Should experiment with automatically selecting the appropriate display when a failure occurs.

Use a touch panel for selecting menu options.

Consider flashing lights for the menu options.

Allow greater selection capability; only use one history page, and bump off old frames.

Use a touch panel display.

Use a touch panel with dedicated menu boxes, like line select CDUs.

The color used to light up the menu option should reflect the severity of the change that occurred.

The menus should be logical subsets, and function buttons should indicate which screen you are currently viewing. A separate acknowledge button might be useful.

For question 10 of the subjective evaluation, the number of subjects assigning each value 1 - 6 to the options (a) - (g) is given in square brackets underneath each option.

10. Please rank the three things you liked best about the display concepts (1=best liked,2,3), and the three things you liked least about the display concepts (4,5,6=least liked).

_____ (a) total amount of information presented	1 [1]	2 [0]	3 [2]	4 [1]	5 [0]	6 [0]
_____ (b) use of color	1 [3]	2 [2]	3 [2]	4 [0]	5 [0]	6 [0]
_____ (c) size of alphanumerics	1 [0]	2 [0]	3 [0]	4 [0]	5 [0]	6 [0]
_____ (d) size of system diagrams	1 [0]	2 [1]	3 [1]	4 [0]	5 [0]	6 [0]
_____ (e) size of history frames	1 [0]	2 [0]	3 [0]	4 [1]	5 [0]	6 [0]
_____ (f) system display format	1 [1]	2 [2]	3 [1]	4 [0]	5 [0]	6 [0]
_____ (g) inclusion of labels on block diagrams	1 [0]	2 [0]	3 [0]	4 [0]	5 [0]	6 [1]

_____	(h) deletion of labels on pictographs					
	1 [0]	2 [0]	3 [1]	4 [1]	5 [0]	6 [0]
_____	(i) history display format					
	1 [0]	2 [0]	3 [0]	4 [0]	5 [0]	6 [2]
_____	(j) menu format					
	1 [0]	2 [0]	3 [1]	4 [1]	5 [0]	6 [0]
_____	(k) illumination of menu option for system with status change					
	1 [3]	2 [2]	3 [0]	4 [1]	5 [0]	6 [0]
_____	(l) ease of switching back and forth between system and history displays					
	1 [0]	2 [1]	3 [0]	4 [0]	5 [2]	6 [0]
_____	(m) ability to select the history display for the currently viewed system only					
	1 [0]	2 [2]	3 [1]	4 [1]	5 [0]	6 [2]
_____	(n) chronological arrangement of history frames on each page of history information					
	1 [0]	2 [0]	3 [2]	4 [2]	5 [0]	6 [0]
_____	(o) lack of updating history information while viewing the history display					
	1 [0]	2 [0]	3 [0]	4 [3]	5 [4]	6 [1]
_____	(p) order in which pages of history information are presented					
	1 [0]	2 [0]	3 [0]	4 [0]	5 [3]	6 [1]

The following four options (q) - (t) were included by several test subjects. The number of subjects assigning each value 1 - 6 to these additional options is also given in square brackets underneath each option.

_____	(q) text formats					
	1 [0]	2 [0]	3 [0]	4 [0]	5 [0]	6 [4]
_____	(r) pictograph formats					
	1 [3]	2 [0]	3 [0]	4 [0]	5 [0]	6 [0]
_____	(s) block diagram formats					
	1 [0]	2 [0]	3 [0]	4 [0]	5 [1]	6 [0]
_____	(t) steady (rather than flashing) menu option					
	1 [0]	2 [0]	3 [0]	4 [0]	5 [1]	6 [0]



Report Documentation Page

1. Report No. NASA TM-101610	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Display Interface Concepts for Automated Fault Diagnosis		5. Report Date December 1989	
		6. Performing Organization Code	
7. Author(s) Michael T. Palmer		8. Performing Organization Report No.	
		10. Work Unit No. 505-67-21	
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-52225		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics Space Administration Washington, DC 20546		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract <p>This report describes an effort which investigated concepts for displaying dynamic system status and fault history (propagation) information to the flight crew. This investigation was performed by developing several candidate display formats and then conducting comprehension tests to determine those characteristics that made one format preferable to another for presenting this type of information. Twelve subjects participated. Flash tests, or limited time exposure tests, were used to determine the subjects' comprehension of the information presented in the display formats. It was concluded from the results of the comprehension tests that pictographs were more comprehensible than both block diagrams and text for presenting dynamic system status and fault history information, and that pictographs were preferred over both block diagrams and text. It was also concluded that the addition of this type of information in the cockpit would help the crew remain aware of the status of their aircraft.</p>			
17. Key Words (Suggested by Author(s)) Aircraft Systems Status, Fault Diagnosis, Displays, Artificial Intelligence		18. Distribution Statement Unclassified-Unlimited Subject Category: 06	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 33	22. Price A03

